C. Allen Bickford

Increasing the Efficiency of

Airphoto Forest Surveys

by Better Definition of Classes

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by

C. Allen Bickford[1]
forester

Northeastern Forest Experiment Station
Forest Service, U.S. Dept. Agriculture

INTRODUCTION

AERIAL PHOTOGRAPHS are now commonly used in forest-inventory work. In the forest-survey work of the Northeastern Forest Experiment Station we are interested most in using them to estimate total volume of a forested area.

Airphotos are useful in forest-survey work because skilled interpreters can detect from them variations in volume per acre; and because they lend themselves to a variety of sampling designs. With our present methods, estimated total volume is based on classification of the forested area

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from airphotos, and ground sampling by field crews to provide data from which mean volumes by classes can be calculated. Appropriate sampling designs have been described by Neyman (5)[2], Chapman (2), Choate (3), Wilson (8), Johnson (4), and Bickford (1).

Volumes may be measured in several units: board feet, cubic feet, cords. For the forest manager, cubic feet is the best unit, because it is independent of how the tree is sawed up or how the pieces may be piled. The goal of the forest survey is to get maximum efficiency in the estimation of total volume in cubic feet. Our accuracy goal is 5 percent per billion cubic feet. In other words, we try to get an estimate of total volume that is within 5 percent of the actual total volume two times in three.

To determine the number of ground plots needed to satisfy this accuracy goal, we use the following formula:

$$M_o = \frac{a(aA + b\sqrt{AB})}{AS^2}$$

in which M_o is number of ground plots, A is cost of a ground plot, B is cost of a photo plot, S is allowable error in cubic feet, and a and b are parameters that depend on the forest itself, the quality of the airphotos, and the skill of the photo-interpreters.

It is evident that the number of ground plots would be smaller if a were smaller. By definition, $a = \sum P_i S_i$, in which P_i is proportion of area in the i^{th} class and S_i is the standard deviation of this class. Now if each S_i were diminished without affecting P_i, it is clear that a too would be smaller. This amounts to saying that if we could reduce variance within classes, we could get equal accuracy with fewer ground plots, at less cost. With other sampling designs different formulas would be used to compute number of ground plots, but this statement would still apply.

In the forest survey we have been estimating stand-size class through photo-interpretation. By so doing, we have a far more efficient design than the line-plot method described by Schumacher and Bull (6). These stand-size classes are defined in terms of board feet and stocking as well as in cubic-foot volume.

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[2] Underlined numbers in parentheses refer to Literature Cited, page 9

Three of these stand-size classes (defined below) are open at both ends in terms of cubic-foot volume; one is open at one end; three other classes with the same limits (0-200 cubic feet per acre) are truly but a single class; and only one class is uniquely defined by cubic-foot volume. It is obvious that there would be less variance of cubic-foot volume within classes if the classes were completely and uniquely defined in cubic feet and if the photo-interpreters could consistently recognize these classes.

To determine if cubic-foot volume classes could be used more efficiently than stand-size classes in the airphoto forest survey, a special study was made in eastern Maryland.

THE STUDY

The study was carried out as part of the regular forest survey of the nine counties of Maryland east of Chesapeake Bay and the Susquehanna River. Numbers of photo plots required were calculated from the design formula, and the plots were marked on the airphotos in the usual manner (with multilith machine). There were 8,044 photo plots in this study. Each plot was classified twice by photo-interpretation: for stand-size class and cubic-foot volume class. The classes used were defined as follows:

Stand-Size Classes

1. Heavy sawtimber	10 M or more bd.ft. per acre
2. Medium sawtimber	5-10 M bd.ft. per acre
3. Light sawtimber	$1\frac{1}{2}$-5 M bd.ft. per acre
4. Heavy poletimber	Less than $1\frac{1}{2}$ M bd.ft. and more than 600 cu.ft. per acre
5. Light poletimber	Less than $1\frac{1}{2}$ M bd.ft., with 200-600 cu.ft. per acre
6. Seedlings & saplings (well stocked)	Less than $1\frac{1}{2}$ M bd.ft. and less than 200 cu.ft. per acre and 40% or more stocked
7. Seedlings & saplings (poorly stocked)	Less than $1\frac{1}{2}$ M bd.ft. and less than 200 cu.ft. per acre and 10-40% stocked
8. Unstocked	Less than $1\frac{1}{2}$ M bd.ft. and less than 200 cu.ft. per acre and less than 10% stocked

9. Nonproductive forest

0. Nonforest (with 8 subclasses)

Cubic-Foot Volume Classes
(in cubic feet per acre)

1. 2,500 or more
2. 1,900 - 2,500
3. 1,250 - 1,900
4. 600 - 1,250
5. 400 - 600
6. 200 - 400
7. 100 - 200
8. 0 - 100
9. Nonproductive forest
0. Nonforest

Numbers of ground plots were estimated for each county on the basis of cubic-foot volume classes, by making a priori estimates of mean and standard deviations of volume by these classes. These plots were examined, classified, and measured according to customary forest-survey methods. Total volume in cubic feet was computed for each plot, and these data were used in the following analytical comparisons. All ground plots were included that had been photo-interpreted as forest land. Statistical efficiency, coefficients of variation, and estimated costs to obtain equal accuracy were computed.

Snedecor (7, p. 248) defines efficiency by the formula:

$$\text{Efficiency} = \frac{\dfrac{1}{S_1^{\,2}} - \dfrac{1}{S_2^{\,2}}}{\dfrac{1}{S_2^{\,2}}} = \frac{S_2^{\,2}}{S_1^{\,2}} - 1 \text{ where } S_2 > S_1$$

This formula is appropriate for comparing two methods when costs of a unit determination are equal or approximately equal.

Variations in volume per plot, based on volume classes, may be computed directly from Neyman's formula 40, neg-

lecting $P_iQ_iN^{-1}$ in the first term. (The entire second term is zero under optimum allocation, which was used in this approach.)

Variance in volume per plot, based on stand-size classes, was computed in a parallel fashion. Adjustment was necessary in the estimation of variance by stand-size class because subsampling was stratified by volume class rather than stand-size class.

Calculated efficiency was 0.15009..., which means that volume-class stratification was about 15 percent more efficient than stand-size class stratification would have been.

The coefficient of variation is the ratio of the standard deviation to the mean. In terms of sampling design, fewer plots are required to meet a specified accuracy when this coefficient is small. Calculated coefficients are shown below for volume classes and stand-size classes.

	Coefficient of variation, by class--[1]							
	1	2	3	4	5	6	7	8
Volume class	43	57	45	60	36	88	99	128
Stand-size class	53	48	51	63	67		137	

Another way to look at it is to estimate the cost to obtain the same accuracy with both methods. Using volume-class stratification with 2,986 photo plots classed as forest land, a variance of 1,659 per plot was obtained with 218 ground plots. If stand-size classes had been used on the same area with the same number of forested photo plots, it is estimated that 253 ground plots would have been required to achieve the same accuracy.

In other words, use of stand-size classes would require 16 percent more of the expensive ground plots. This amounts to an estimated saving of $1,215 in the nine counties through the use of volume-class stratification.

In passing, it should be mentioned that area can be estimated by stand-size class, forest type, or any other similar category, even though photo-interpretation is on the basis of volume in cubic feet. This can be done by supplemental classification of each plot or point.

In the forest survey, area by stand-size class is obtained by classifying ground plots, calculating proportions by volume class, and summing over-all volume classes. To obtain this additional information, classification can be based on either ground examination or photo-interpretation. If there is a difference in accuracy or cost, the more accurate or less costly method should be used. Otherwise it is a matter of convenience.

APPLICATION OF RESULTS

General

It has been pointed out that in the forest survey efficiency is increased when variance within classes is reduced. The study in eastern Maryland has shown that there is less variance in cubic-foot volume when cubic-foot volume classes are used in photo-interpretation classification of the forest stands. It is reasonable to expect similar results with other units of measure.

Variance within classes may be reduced in other ways. We photo-interpret a stand at least 1 acre in size, but our ground plot is only 1/5 acre in size. Use of identical areas in each stage of sampling should result in less variation; but it might be too costly.

Variance may also be reduced by increasing the size of the ground plots. For this to be truly more efficient, the number of plots would have to be reduced enough to more than offset the added cost per plot.

Inventory cost is reduced by any reduction of variance within classes, where stratified sampling is used, if unit costs remain the same or if their increase is small in comparison with the number of plots saved.

In Forest Survey

As already pointed out, use of cubic-foot volume classes in photo-interpretation during the survey of nine counties of eastern Maryland resulted in an estimated saving of $1,215.

A comparison was also made for the State of Connecticut. There, using our design formulas and cubic-foot volume classes in photo-interpretation, we calculated that 201 ground plots and 4,531 photo plots would be required to obtain an accuracy of 5 percent per billion cubic feet.

If stand-size class were used instead, 395 ground plots and 8,692 photo plots would be required to obtain the same accuracy. Comparative estimated costs are $15,560 for use of stand-size classes and $7,940 for cubic-foot volume classes.

These advantages are not limited to the design we use. Similar gains should be expected from any design that takes advantage of the reduced variance within classes. The triple-sampling design described by Chapman (2) is one that should produce comparable benefits. The only requirements are availability of airphoto coverage and actual use of the reduced variance within classes.

In Ordinary Timber Cruising

In applying airphotos to the usual timber-cruising problem, it has been common practice to delineate classes on the photos as the first step in their use. In many cases, this delineation is needed for best use of airphotos by a forest manager.

He should realize, however, that this delineation is not always necessary. If he is interested only in an estimate of total volume, he can get maximum efficiency without delineation (1). This is true because there is less variance within classes defined by classifying a series of small photo plots than when these same classes are delineated to a minimum area of 5, 10, or 40 acres.. In other words, there is more variation from one 1/5 acre to another when the minimum area is 5 acres than when it is 1 acre.

When classes are delineated, efficiency is improved by any device that reduces within-class variance. Number of plots for a class is estimated by dividing the variance by the square of acceptable error, or some function of this ratio. If the timber cruiser is interested in board-foot volume, he should use classes defined in board feet for his photo-interpretation. If he wants cords, he should classify on the basis of cords. Of course, if volume in cords is obtained by converting from cubic feet, the classes should be defined in cubic feet.

Without delineation, cruising with the use of airphotos uses the same sampling design as the forest survey. The principal difference would be a greater concentration of field and photo plots, that is, acres per plot would be smaller. Application of the results would be exactly the same as described here for the forest survey.

CONCLUSIONS

From this study in eastern Maryland, we have concluded that, in photo-interpretation, cubic-foot volume classes are better than stand-size classes for meeting an accuracy standard in cubic feet. Efficiency of a forest inventory might be increased with this method by: (1) using identical areas for both photo-interpretation and ground examination; (2) increasing the size of a ground plot; and (3) substituting classification for delineation in ordinary timber cruising.

This study has convinced us that cubic-foot volume classes should be used in forest-survey photo-interpretation. Stand-size classes have been used 5 years for this purpose, and we cannot expect much further improvement without new and superior techniques. It is possible that, with more experience, an even better job will be done by using cubic-foot volume classes.

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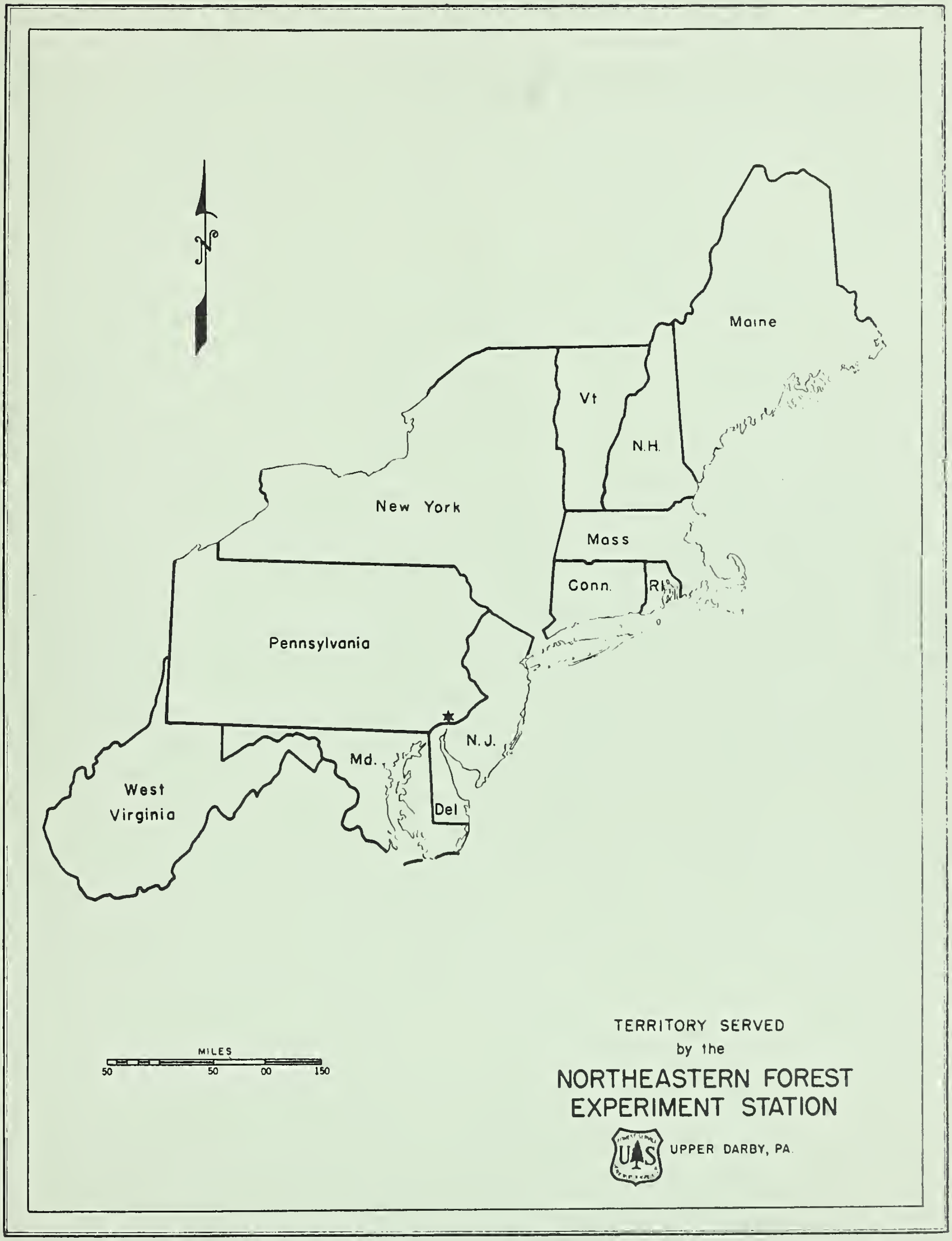
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